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Modelling the spread of foot-and-mouth disease virus in France

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Abstract
Models have been used for some times to help in decision making around Foot-and-Mouth disease (FMD) outbreaks. Most of these models can be seen as training tools, as Western countries, where many of them have been developed, had been free of FMD during many years. More recently, with the sanitary measures -with a ban on vaccination- implemented in Europe, a new demand arose. Here we resume two different models. The first one tries to mimic a FDM outbreak, adapted to the kind of farming present in the area of the epidemic. The other one helps to forecast airborne virus spread around an infected premise.

Keywords
Foot-and-Mouth disease virus, modelling, forecasting, airborne spread, France.

I - Introduction

As in many other livestock producing countries, foot-and-mouth disease (FMD) is of great concern in France. The modelling of the spread of the virus, in case of an outbreak, must be understood within the global surveillance and control scheme developed in the early 1990s, after the implementation of the new European Union (EU) strategy, banning the use of vaccination on the first of January 1992.

It must be recalled that :
-only cattle were vaccinated, which means already that our different sensitive species (cattle : 20 millions, sheep and goats : 10 millions, swine : 13 millions) are not playing the same role in the epidemiology of the disease, as it will be seen later on,
-and that vaccination is just one among different other essential tools to face FMD risk.

FMD risk can be seen in three steps :
Introduction risk. When the virus has been eradicated from an area, it must be brought back, either as an escape from a laboratory either through trade.
Exposition risk. The virus must arrive~~s~~ on a sensitive individual (sensitive species not vaccinated)
Spreading risk. From a primary case, the virus starts an epidemic.

The modelling of the spread of FMD virus has been developed, in this country, as a tool to help decisions makers to manage an outbreak, after its identification. An early identification is the major step in case of any new FMD epizootic, and depends on surveillance capabilities in trade (international and national) and in farms. This step is fundamental, as can be seen from the recent (Winter - Spring 2001) experience of the United Kingdom (UK) situation. Apparently, the primary outbreak was only found a few days after the index case (case number 1), the primary outbreak being only case number 5, and having been with the virus for three weeks before being identified, only in a trace back survey. Whatever the models, such a delay will be really difficult to compensate.
We will try to summarize rapidly the global national strategy, to be understood within European Union sanitary politics, and then present the models.

II - Discussion

II – 1 - FMD former contingency plan

The former French sanitary strategy was implemented in 1961, with a compulsory vaccination of all cattle once a year, linked with slaughtering and destruction of all sensitive animals in outbreaks, followed by disinfection of the premises, and control of animal and product movements around any outbreak. The aim was the eradication of the disease and of the virus. This was already obtained in the 1980s indeed. So, as early as in 1985, an European discussion started on what to do for 01 January 1993, time of opening of the free EU market. In 1985, three countries were not vaccinating their cattle (Denmark, Republic of Ireland and UK), and the others were performing this vaccination. Two options were opened to discussion : to vaccinate cattle in all EU countries or to ban all vaccination.

This lead to epidemiological and economical studies (for France see Moutou 1990, Dufour & Moutou 1994, Mahul & Durand 2000) showing that the difference, in term of risk, was much more on the probability of extension of an epizootic than on the probability of introducing the disease and having a first outbreak (exposition and revelation risks). Even in 1990, it was clear that the virus had been eradicated of the country (in fact from Western Europe at least), since no outbreak had been detected in France since 1981, when, on the average, only 50% of the sensitive animals were protected by the vaccine. Sheep, goats and pigs were not protected and only 80% of the cattle could be considered as vaccinated and protected. In some regions (Brittany for instance) this ratio vaccinated/sensitive was as low as 20%. The question of a wild reservoir had also been addressed. Possibilities of contact between wild deer, wild mountains ruminants and wild boars, with domestic livestock did (and still) exist, when no outbreak was ever recorded. In addition, translocations of wild ruminants and of wild boars all over the country for repopulation or for hunting purposes lead to opportunities for virus and antibodies surveys, which always stayed negative.

II – 2 – FMD new contingency plan

The new contingency plan against FMD in France is organised around 10 different actions.
What to do in case of suspicion ?
Epidemiological questionnaire
What to do in case of confirmation ?
The slaughtering of animals
The burying of animals
Disinfection
Protection and surveillance areas
What to do with animal products issued from these areas ?
Emergency vaccination (if decided)
What to do in artificial insemination centres ?
These documents have been issued as letters to the local veterinary services.

The legislation was arranged to take into account the new scheme. The question of reimbursing the slaughtered animals (in outbreaks and as prevention) was also addressed in the legislation. Information and training had been sent and performed to and for farmers and farmer organisations as well as to and for veterinary services and private practitioners. A national plan had been set up, with a local application in every French department (about 90 departments with farm animals, plus 10 overseas departments and territories).

The FMD surveillance is under the responsibility of the Ministry of Agriculture, and its National Veterinary Services, with the technical assistance of the French Food Safety agency (AFSSA, epidemiology and virology units, either Lyon, either Maisons-Alfort, i.e. two localisations). The AFSSA, for instance, is in charge of the diagnosis of FMD.

The National Veterinary Services are also organised with a veterinary inspection service in every department. In case of a suspicion, eventually followed by an outbreak, they are in charge of its management will the local authorities. They are the one sending samples in case of clinical suspicion to AFSSA laboratories. Of course, the AFSSA laboratories can be joined any day any hour. Following the situation, AFSSA team may be sent to join the local veterinary services. Before the sending of any sample, a first discussion by telephone from the suspected farm to the AFSSA team may help to get a better idea of the situation. In case of sample sent, it gives also time to the virology team to save time by preparing itself and all the biological reagents.

II – 3 – Epidemiological data

From experiences gained all over Europe, as well as outside, it became clear that not every species is playing the same role in FMD epidemiology.

-Cattle are usually showing the clearest clinical signs and can be seen as sentinel animals.

-Sheep and goats are not showing easily clinical signs and are then supposed to be a real hazard in case of suspicion. This did happen in February and March 2001 in France. The virus did came with sheep but no lesion was noticed when examined and slaughtered as a prevention measure. The two outbreaks were recorded on cattle : the first one was a dairy herd in a farm just next door of a farm having imported sheep from UK some days earlier, from a British farm that became case number 11 in the UK. The second one was recorded on a cattle mixed with sheep coming (illegal movement, which is much more difficult to forecast and to compute than just airborne virus) from this same farm having imported sheep from the UK.

-Then comes the swine, which usually show behavioural and clinical signs, but which are the main epidemiological risk in our farming systems as they may spread virus by airborne route in a massive way and as they are usually bred in huge units in high animal density areas. If ruminants may excrete 10 to the 5 virus particles per animal and per day, pigs can excrete up to 10 to the 8 virus particles, which means that a single pig is equal to, at least, 1000 cattle. Infected pigs is the situation that we are fearing the most, and this is the situation in which modelling the spread of the virus through airborne route may be the more useful.

II – 4 – An extended state-transition model

A global epidemiological modelling approach can be seen in Durand & Mahul (2000). These few lines are just a summary of this paper. The model is based upon a state-transition model developed from a Markov chain. The unit of concern is an average composite herd and the time period is half a week. Seven herd-level health states are defined : exposed-susceptible, non-exposed-susceptible, incubation, invasion, clinical, immune and dead. Dissemination rates (DR) were based upon simulation results obtained from a specific discrete-event simulation model, and the silent development of FMD in affected herds before the diagnosis is taken into account. Different DR were used to simulate different breeding areas with different farms and animals densities. Slaughtering of infected and contact herds is the most effective strategy.

Up to now, most of epidemiological modelling had been using UK 1967-1968 epidemic data. It should be important to get new sets of data to compare situations closer from our 2001 farming systems.

II – 5 – Long distance (over sea) FMD virus spread modelling

One more word to say that here on the continent, we only consider the airborne spread overland around an outbreak. In this case, the area at risk may be seen within a 10 kilometres radius of the infected premise. In the UK, since the early 1980s, an other long range model have been developed, that considers the transportation of FMD virus over sea on a much longer distance. The 1981 outbreak in Brittany (Côtes d'Armor department) is supposed to have sent virus to Jersey island (Channel islands) and to Wight island (250 km to the North), just close to British shores. This is possible as sea surface is smoother that land surface (relief, buildings, vegetation) and when sea temperature is lower than air temperature (Gloster et al., 1981). However, in term of probability, this risk must certainly be seen as very low. During the 2001 UK epizootic, up to now, very few pig farms have been involved and none along the Southern shores. This possibility has however been taken into account on the continent and the global meteorological condition over the British Channel had been monitored since the end of February.

II – 6 – Over land FMD virus spread modelling

The modelling we are using has been described in Moutou & Durand (1993) and came from a model first developed by French Meteorological and Atomic Energy agencies for the surveillance and control of nuclear power plants. The main adjustments are linked to the fact that we changed radioactive isotopes data by FMD virus particles data. The virus emission is seen as a plume leaving the infected premise, carried along by air, following the prevailing local winds (direction and speed). The viral concentration within any elementary puff is decreasing following a Gaussian dispersion in all three directions (vertical, horizontal in the wind direction and horizontal in a perpendicular direction). Relative humidity is used as a cut off (under 60%, no virus will survive) and a vertical atmospheric stability parameter gives a two options decision in the model : higher stability means higher concentration on a longer distance from the origin (or during a longer time after emission).

In fact, the model can be run using the plume or the puff situation, following the local conditions. The idea is not to be mathematically perfect, but to be pragmatic, thinking of the possible extension of a FMD outbreak in the surrounding farms.

We also need to know the species involved, the number of animals within each species and the estimated age of the oldest lesions. These data are sent to us by the local veterinary services, in charge of a suspicion, even before its confirmation in the laboratory (here also at the AFSSA, LERPAZ, virology unit). Then we turn to the National Meteorological agency, with whom we have a convention, to receive the meteorological data we need, from the nearest meteorological station found, and in the proper format. This can be performed any day, any hour, as confirmed during this last epidemic, which could also be seen as a real size exercise….

It must be understood that there is no meteorological forecasting, just because we are using past meteorological data. But, from these data, and from the age of the lesions, we can suggest where the virus may have already been spread by the airborne route, and animals already incubating, as we know that infected animals may start excreting virus by the respiratory route one (or even two) day(s) prior to the first visible vesicle. We also suppose that all sensitive animals are excreting virus in the same time, which is certainly not true, as the virus may take some days to infect a whole herd. Here again the idea is to be helpful and pragmatic. The results are iso-concentration lines within which a certain quantity of virus may have been inhaled by a sensitive animal. Depending on the species, the area my be larger or smaller. When we look for the largest (worse) areas, which is usually the case, we use cattle as sentinel in the model. Their larger size make them more sensitive with about 100 litres of air sampled by minute. If only sheep or pigs are known to be present in the surroundings, it is possible to adapt the model for the at risk area linked to the right species (only 10 to 20 air litres sampled by minute by a sheep).

The iso-concentration lines may be cumulated during the whole duration of the emission, i.e. from the beginning of virus spreading to the slaughtering of the infected animals, or limited to a 24 hours period, which may be more close to reality. The four lines drawn by the model are

the lines limiting areas which received, on the average, at least 100, 50, 10 and 1 particles. The 1 particle is virtual but easy to get from the computer ! The 10 particles line will be interpreted following the local farming. The area within the 50 (and 100) particles are the main at risk areas.
This partitioning may help to manage the surveillance (10 km radius) and protection (3 km radius) zones around an outbreak. For instance, it could be useful to have different teams to prospect at risk areas, compared to teams visiting farm with no known airborne risk. It is also possible to decide from this information to perform some preventive slaughtering of pig farms, considering the risk they may get infected and spread a much more larger cloud of virus. This was done in 1993, in the Verona epidemic in Northern Italy (Maragon et al 1994). Two pig farms, very close from the fourth outbreak, were stamped out before any clinical was noticed. When we forecasted the area on which they could have spread virus, supposing they were infected, the number of farms was such that it was decided not to wait (maps 1 and 2). On the other hand, with the two outbreaks of March 2001 in France, where we also forecast the possible airborne spread of the virus, the risk area was only a few tens of metres away, within the land of the two farms. This is linked to the fact that in both case only ruminants were concerned.

III – Conclusion

The reality of 2001 outbreaks brought a lot of new data and show the difference between training software and real epidemics. It may be possible, in even sophisticated ways to model the spread of FMD virus. It is much more difficult to model human behaviour or (legal and illegal) sheep movements. However, they may be the key factors in controlling any outbreak.

IV – Acknowledgements

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V - References

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